

DESCRIPTION  
GAS DETECTOR

TECHNICAL FIELD

5 The present invention relates to a gas detector for detecting hydrogen leakage and humidity.

BACKGROUND ART

There are intense activities in recent years for development of fuel cells  
10 that generate electric power from hydrogen and oxygen in the air. These activities are motivated by three reasons below.

First, they are excellent power generating methods in view of the environmental protection, because substance being released during generation of electricity is only water. Secondly, they save energy because  
15 they are fundamentally superior in efficiency of generating the electric energy. Thirdly, they have an advantage of using even thermal energy by collecting heat produced during generation of electricity. They therefore hold expectation as the last resort to solve the energy and environmental problems in the global scale.

20 Such fuel cell systems as discussed above are considered useful for application to home-use cogeneration systems as well as automobiles.

The fuel cell systems are expected to grow more and more in the future as alternative sources of energy to replace the existing thermal power generation and gasoline engines that use fossil fuel. Because the fuel cells  
25 use hydrogen for the fuel, it is important that they are provided with safety measures. In other words, it is indispensable for the fuel cells to be equipped with hydrogen concentration detectors for detecting leakage of

hydrogen to ensure the safety. There have been hitherto proposed some devices as such hydrogen concentration detectors that detect hydrogen concentration by monitoring temperature change of heater elements based on the principle that a coefficient of thermal conductivity of hydrogen is  
5 extremely large as compared to other gases. When hydrogen gas reaches a heater element which is in a state of thermal equilibrium in the air, for instance, there occurs a change in amount of heat being taken away from the heater element, and causes it to lose the thermal equilibrium. As a result, temperature of the heater element changes according to a level of  
10 the hydrogen concentration. The hydrogen concentration detector uses a temperature sensor element to electrically detect this temperature change. Platinum temperature-measuring elements are well known as the heater elements, and the temperature sensor elements used for such hydrogen concentration detectors. Since platinum has a relatively high specific  
15 resistance among metals, it generates heat in itself when an electric current is fed through. In addition, because platinum also has a relatively high temperature coefficient of resistance among metals, it can be used for detection of temperature change corresponding to the hydrogen concentration through a change in resistance. A gas detector contrived to  
20 use the above method is disclosed in the official publication of unexamined Japanese utility model, No. S62-12861. It uses two detectors of different heating temperatures, and a factor multiplier and an arithmetic unit to solve a set of simultaneous equations obtained from outputs of the two detectors. This gas detector can thus measure a level of concentration of  
25 the gas to be detected while eliminating influence of interfering gases.

However, the above gas detector of the prior art shows a drawback when there is water vapor present as an interfering gas in the gas to be detected.

In other words, a resistance of platinum changes precisely in proportion to the level of hydrogen concentration only if there is no water vapor. However, the water vapor, if present, also changes the resistance of platinum. As a result, the gas detector is unable to determine what has  
5 caused the change in resistance, whether it is due to hydrogen, water vapor, or both of them in coexistence. It is for this reason to solve the above problem that the gas detector of the prior art makes arithmetic operation of the simultaneous equations to eliminate influence of the interfering gases. However, water vapor shows such characteristics that its  
10 coefficient of thermal conductivity rises with increase in absolute humidity, but start descending once the coefficient value reaches a peak level in an atmosphere in which the water vapor having polarities is mixed with unpolarized air, hydrogen and the like, although the coefficient value of water vapor is extremely smaller than that of hydrogen when present  
15 separately.

Therefore, in the case where a large amount of water vapor is assumed present in relation to hydrogen, a coefficient of thermal conductivity in the mixture of the water vapor and hydrogen rises once with increase in absolute humidity and descends after it reaches the peak level, as  
20 previously stated, when detecting hydrogen leakage. That is, the mixture shows a characteristic that the coefficient of thermal conductivity changes in a form of quadratic curve. Therefore, if a gas detector is adapted to use the prior art technique of solving the simultaneous equations as described above, it calculates only a level of hydrogen through arithmetic operation  
25 of the simultaneous equations in two unknowns, and has the following problems. That is, the operation is very complex as a signal processing technique of the sensor, and it gives rise to problems with regard to

detecting accuracy, multiplicity of uses, cost of putting it to practical use, and so forth.

Accordingly, it is an object of the present invention to provide a gas detector having a capability of detecting hydrogen concentration by  
5 distinguishing it from moisture in the environment wherein the hydrogen coexists with water vapor.

### SUMMARY OF THE INVENTION

There is provided a gas detector comprising: a high-temp exothermic  
10 detector unit having a high-temp exothermic gas sensor element and a high-temp exothermic temperature sensor element, each made of a resistor of which a resistance changes responsive to temperature, the high-temp exothermic gas sensor element exposed to a gas being detected, and the high-temp exothermic temperature sensor element sealed in an  
15 unperforated casing filled with dry air and maintained to generate heat to a temperature substantially equal to a self-heating temperature of the high-temp exothermic gas sensor element as measured in dry air; and a low-temp exothermic detector unit having a low-temp exothermic gas sensor element and a low-temp exothermic temperature sensor element,  
20 each made of a resistor of which a resistance changes responsive to temperature, the low-temp exothermic gas sensor element exposed to the gas being detected, and the low-temp exothermic temperature sensor element sealed in another unperforated casing filled with dry air and maintained to generate heat to a temperature substantially equal to a  
25 self-heating temperature of the low-temp exothermic gas sensor element as measured in dry air, wherein the self-heating temperature of the high-temp exothermic gas sensor element and the high-temp exothermic temperature

sensor element of the high-temp exothermic detector unit is set to be different from the self-heating temperature of the low-temp exothermic gas sensor element and the low-temp exothermic temperature sensor element of the low-temp exothermic detector unit as measured in the dry air. The  
5 gas detector performs processes of: converting resistance values of the individual gas sensor elements that change responsive to hydrogen concentration, humidity and an ambient temperature, and resistance values of the individual temperature sensor elements that change responsive to the ambient temperature into electrical gas-level outputs  
10 corresponding to the hydrogen concentration and the humidity; normalizing the gas-level outputs gained from the individual detector units by using a hydrogen sensitivity conversion factor obtained under a known level of hydrogen concentration; obtaining a humidity-level output derived as a difference between the normalized outputs; and producing outputs  
15 representing levels of the hydrogen concentration and the humidity by correcting the normalized outputs with a humidity-level correction formula established through a correlation of a humidity-level correction value obtained from the humidity-level output gained under an environment of known humidity level and the individual normalized outputs responsive to  
20 the humidity.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is a cross sectional view showing a structure of a gas detector according to a first exemplary embodiment of the present invention;

25 Fig. 1B is a laterally sectioned view taken along a line A - A of the gas detector according to the first exemplary embodiment of this invention;

Fig. 2 is a longitudinally sectioned view of a thermistor used in the gas

detector according to the first exemplary embodiment of this invention;

Fig. 3 is a perspective view illustrating a method of assembling a detector unit of the gas detector according to the first exemplary embodiment of this invention;

5 Fig. 4 is a cross sectional view illustrating an installation method of the gas detector to a pipe, according to the first exemplary embodiment of this invention;

Fig. 5 is a diagram showing a circuit configuration of the gas detector according to the first exemplary embodiment of this invention;

10 Fig. 6A and 6B are graphs representing hydrogen concentration and output characteristics under a dry air environment of the gas detector according to the first exemplary embodiment of this invention;

Fig. 7 is a graph representing a humidity and output characteristic of the gas detector according to the first exemplary embodiment of this invention;

15 Fig. 8A and 8B are graphs representing output characteristics after corrective operation of the gas detector according to the first exemplary embodiment of this invention;

Fig. 9A is a cross sectional view showing a structure of a gas detector according to a second exemplary embodiment of this invention;

20 Fig. 9 B is a laterally sectioned view taken along a line A - A of the gas detector according to the second exemplary embodiment of this invention;

Fig. 10 is a diagram showing a circuit configuration of the gas detector according to the second exemplary embodiment of this invention;

25 Fig. 11 is a graph representing a humidity and output characteristic of the gas detector according to the second exemplary embodiment of this invention; and

Fig. 12A and 12B are graphs representing output characteristics after

corrective operation of the gas detector according to the second exemplary embodiment of this invention.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

5 Referring to the accompanying drawings, description is provided hereinafter of the exemplary embodiments of the present invention.

The drawings are intended to schematically show only positions of individual elements, and they therefore do not reflect their dimensions accurately. In the present invention, a high-temp exothermic gas sensor  
10 element (hereinafter referred to as "GDH") defines a gas sensor element that generates heat by itself to maintain it in a state of high temperature for the proper function as a sensor element.

In addition, a low-temp exothermic gas sensor element (hereinafter referred to as "GDL") defines another gas sensor element that generates  
15 heat by itself to maintain it at a temperature lower than that of the GDH.

It is desirable that these two temperatures differ by 10°C or greater, but a difference of about 50°C is more desirable.

Likewise, a high-temp exothermic temperature sensor element (referred to as "TDH") defines a temperature sensor element that generates heat by  
20 itself to maintain it in a state of high temperature for the proper function as a sensor element. Also, a low-temp exothermic temperature sensor element (referred to as "TDL") defines another temperature sensor element that generates heat by itself to maintain it at a temperature lower than that of the TDH. It is also desirable that these two temperatures differ by  
25 10°C or greater, but a difference of about 50°C is more desirable. It is desirable in addition that the low temperature maintained by the GDL and TDL is 100°C or higher.

Furthermore, a high-temp exothermic detector unit (referred to as "DPH") comprises the GDH and the TDH, and it additionally includes a circuit for operating them.

Similarly, a low-temp exothermic detector unit (referred to as "DPL")  
5 comprises the GDL and the TDL, and includes a circuit for operating them.  
(First Exemplary Embodiment)

Fig. 1A shows GDH 1a, TDH 1b, GDL 2a and TDL 2b. Each of these elements is composed of a thermistor, of which a structure is shown in Fig. 2. Heat generating resistors of any kind can be used as these elements, if  
10 resistances are variable responsive to temperature change. Thermistor element 4 used here is made of a sintered oxide compound composed of manganese, cobalt, copper and vanadium, which is cut into a disc-like shape of 1.2mm in diameter and 0.2mm in thickness. B-constant defining a temperature characteristic of it is 2,300K. However, any element having  
15 a value in a range of approximately 1,000 to 3,000K may also be used. Thermistor element 4 is provided with electrodes 5 formed on both surfaces thereof by printing and firing conductive paste of silver, palladium and platinum based material. Lead wires 6 made of a platinum wire of 0.15mm in diameter are connected electrically and mechanically to the  
20 both electrodes 5 with the conductive paste. Glass layer 7 of a low melting point is formed to cover the entire exterior surface of thermistor element 4, including the electrodes 5 and parts of lead wires 6.

Glass layer 7 is formed by coating a pasty form glass powder having a firing temperature of 550°C mixed with organic solvent.

25 Thermistor element 4 is concealed entirely in glass layer 7 to thus complete thermistor 8.

Thermistors 8 produced in the manner as described above are prepared



here for a total of four pieces.

Next, electrical and mechanical connection of each thermistor 8 is made by resistance welding lead wires 6 to pins 10 fixed to base 9, as shown in Fig. 3 (shown by marks "x" in the figure). The four pieces of assembled  
5 elements are used as GDH 1a, TDH 1b, GDL 2a and TDL 2b respectively. Each of TDH 1b and TDL 2b is enclosed in unperforated casing 11b in a space filled with dry air, as shown in Fig. 1A and Fig. 1B. The unperforated casing 11b and base 9 are bonded and sealed by projection welding.

10 The casing is formed of a metal. It is desirable to use stainless steel in the light of corrosion resistance and weldability.

TDH 1b and TDL 2b constructed as above output voltages across their end terminals corresponding to their respective temperatures inside the gas detector without being influenced by the gas to be detected. Each of  
15 GDH 1a and GDL 2a is covered with perforated casing 11a having through holes of 1.2mm in diameter at four locations as shown in Fig. 1A. Perforated casing 11a and base 9 are bonded and sealed by projection welding.

In the structures including perforated casings 11a and unperforated  
20 casings 11b, the temperature sensor elements (TDH 1b and TDL 2b) and the gas sensor elements (GDH 1a and GDL 2a) are made to be equal in their thermal capacity, so that both of these sensor elements have generally equal heat generating characteristic.

Because of the above structures, the heat generating characteristic of  
25 TDH 1b becomes substantially equal to that of GDT 1a. In addition, the heat generating characteristic of TDL 2b also becomes substantially equal to that of GDL 2a. They can thus make an accurate temperature

correction to the effect of ambient temperature. Furthermore, TDH 1b shows a temperature rise profile similar to that of GDH 1a during startup of the gas detector. TDL 2b also shows a temperature rise profile similar to that of GDL 2a.

5 High-speed startup of the gas detector can be made possible as a result of the above. GDL 2a enclosed in perforated casing 11a and TDL 2b enclosed in unperforated casing 11b are connected together with heat conductive plate 33 made of a material of high coefficient of thermal conductivity such as copper, aluminum and the like material. Likewise,  
10 GDH 1a enclosed in perforated casing 11a and TDH 1b enclosed in unperforated casing 11b are connected together with another heat conductive plate 33. Accordingly, the individual sensor elements are kept in a generally equal state of thermal conduction between perforated casings 11a and unperforated casings 11b provided around the sensor  
15 elements 1a, 1b, 2a and 2b and the surrounding environment.

This makes the gas detector capable of performing highly accurate detection even under transitional changes in the ambient temperature, in addition to achieving a good effect for quick startup. For GDH 1a, TDH 1b, GDL 2a and TDL 2b, pins 10 are connected electrically and mechanically at  
20 their one ends to circuit board 15 by soldering. They are then housed in container 16 having a hexagonal exterior as shown in Fig. 1B.

Flat heater 34 is placed in the vicinity of GDH 1a, TDH 1b, GDL 2a and TDL 2b as shown in Fig. 1A. Heater 34 is energized for about five seconds to a temperature of 200°C immediately after the startup of the detector.

25 Operation of the heater 34 heats up thermistors 8 to thereby lower their resistances to such values that make self-heating possible even when the ambient temperature is so low that the resistances of thermistor elements

4 are substantially large. The detector can be thus made operative even in a low temperature. In the first exemplary embodiment here, although heater 34 is shown as being operated during every startup, it may be operated only when the ambient temperature is low. For this purpose, 5 microcomputer 32 may be used to monitor any of resistances and voltage values of thermistors 8, and heater 34 is operated only when the temperature is determined low, or the resistances are high. This can also save power consumption.

Filter 18 made of a sintered metal is fitted in gas intake opening 17. 10 Filter 18 has a circular shape, and it is disposed in a manner to project outward from container 16. When the gas to be detected contains moisture, there is a possibility that dew condensation occurs inside container 16 depending on the condition of ambient temperature.

The gas detector is therefore placed in such an orientation that gas 15 intake opening 17 faces the direction of gravity, so as to let the condensed water flow out smoothly and drained to the outside of filter 18 by the gravity. Container cover 24 having conductor cable 23 disposed beforehand in a manner to pass through is placed above circuit board 15 inside container 16, and it is secured to container 16 by crimping. 20 Furthermore, a space between circuit board 15 and container cover 24 is filled in its entirety with moisture resistant resin 25 injected through a filling opening (not shown in the figure) provided in container cover 24, and it is cured. The gas detector thus completed is fixed to a location where detection of gas concentration is desired, by tightening screw 26 25 formed on a peripheral portion of container 16. In the case of detecting gas concentration in a piping system, mounting hole 28 for the gas detector is formed in a part of pipe 27, as shown in Fig. 4. The gas detector is

secured by tightening screw 26 into mounting hole 28. In this structure, since gas intake opening 17 is located away from the main gas stream inside pipe 27, an undesirable influence attributed by a flow speed of the main gas stream can be alleviated.

5 Description is provided next of an operation of the gas detector.

As shown in Fig. 5, GDH 1a, TDH 1b, GDL 2a and TDL 2b are connected in series with fixed resistors 29a, 29b, 29c and 29d respectively. Here, fixed resistors 29a and 29b are of  $220\Omega$  in resistance and fixed resistors 29c and 29d are of  $500\Omega$  in resistance respectively. These resistors thus  
10 control the heating temperatures of GDH 1a and TDH 1b to approximately  $190^{\circ}\text{C}$  and those of GDL 2a and TDL 2b to approximately  $140^{\circ}\text{C}$ . D.C. power source 31 is connected to these circuits and supplies electrical power of 15V.

Describing now pertains to a method of controlling the individual  
15 elements at constant heating temperatures. In this first exemplary embodiment, two sensor elements 1a and 1b of DPH 35a, and two sensor elements 2a and 2b of DPL 35b are so controlled that their heating temperatures when measured in dry air are kept constant irrespective of an influence of the ambient temperature.

20 The two sensor elements 1a and 1b of DPH 35a are controlled in a manner as described hereinafter to make their heating temperatures constant.

Element resistance regulating circuit 36a in DPH 35a consists of fixed resistor 29e of  $11\text{k}\Omega$  and another fixed resistor 29f of  $33\text{k}\Omega$  connected in  
25 series. A voltage across the both ends of fixed resistor 29f serves as a control voltage.

Ambient temperature detecting circuit 37a comprises fixed resistor 29b

of  $220\Omega$  connected in series to TDH 1b.

A voltage across the both ends of fixed resistor 29b is a to-be-controlled voltage. Here, a voltage applied to element resistance regulating circuit 36a, gas detecting circuit 38a comprising the series connection of GDH 1a  
5 and fixed resistor 29a of  $220\Omega$ , reference voltage circuit 39a and ambient temperature detecting circuit 37a is regulated through an operational amplifier, a transistor and the like in response to changes in the ambient temperature, in a manner to equalize the to-be-controlled voltage with the control voltage.

10 Since the resistances of TDH 1b and GDH 1a are kept to be constant at all times as described above, the heating temperatures of them can be maintained constant.

On the other hand, heating temperatures of the elements at the side of DPL 35b are controlled constant in the following manner. Element  
15 resistance regulating circuit 36b in DPL 35b comprises fixed resistor 29g of  $43k\Omega$  and another fixed resistor 29h of  $100k\Omega$  connected in series.

A voltage across the both ends of fixed resistor 29h serves as a control voltage. Ambient temperature detecting circuit 37b comprises fixed resistor 29d of  $500\Omega$  connected in series to TDL 2b. A voltage across the  
20 both ends of fixed resistor 29d is a to-be-controlled voltage. A voltage applied to element resistance regulating circuit 36b, gas detecting circuit 38b comprising the series connection of GDL 2a and fixed resistor 29c of  $500\Omega$ , reference voltage circuit 39b and ambient temperature detecting circuit 37b is regulated through an operational amplifier, a transistor and  
25 the like in response to changes in the ambient temperature, in the manner as described above, to equalize the to-be-controlled voltage with the control voltage.

Since the resistances of TDL 2b and GDL 2a are kept to be constant at all the time as described, the heating temperatures of them can be controlled constant.

Accordingly, since the ambient temperatures of the individual sensor  
5 elements are kept generally uniform, they reduce changes in coefficient of thermal conductivity of the gas to be detected due to the effect of temperature. As a result, the gas detector can detect gas concentration with high accuracy.

This embodiment also provides an advantage of shortening a warm-up  
10 time because it controls the self-heating temperatures of the individual sensor elements constant immediately after the startup of the gas detector.

Describing next pertains to the steps of signal processing to obtain a gas-level output from each of the detector units.

In DPH 35a, signal processing is performed in the following manner to  
15 obtain a gas-level output. Reference voltage circuit 39a for producing a reference voltage comprises a series connection of fixed resistor 29i of a resistance value smaller than  $11\text{k}\Omega$ , fixed resistor 29j of  $33\text{k}\Omega$  and variable resistor 29k. A voltage across both ends of fixed resistor 29j is taken as the reference voltage. Gas detecting circuit 38a comprises fixed resistor  
20 29a of  $220\Omega$  connected in series to GDH 1a. A voltage across both ends of fixed resistor 29a is a gas-level output voltage, which is used in the signal processing to obtain a difference in voltage potential in comparison to the reference voltage. If there is a difference between the reference voltage and the gas-level output voltage in the air containing no hydrogen and  
25 humidity, a resistance of variable resistor 29k is adjusted to eliminate the difference.

Signal processing in DPL 35b is performed in the following manner to

obtain a gas-level output. Reference voltage circuit 39b for producing another reference voltage comprises a series connection of fixed resistor 29l of a resistance value smaller than  $43\text{k}\Omega$ , fixed resistor 29m of  $100\text{k}\Omega$ , and variable resistor 29n. A voltage across both ends of fixed resistor 29m is  
5 used as the reference voltage.

Gas detecting circuit 38b comprises fixed resistor 29c of  $500\Omega$  connected in series to GDL 2a. A voltage across both ends of fixed resistor 29c is a gas-level output voltage, which is used in the signal processing to obtain a difference in voltage potential in comparison to the reference voltage. If  
10 there is a difference between the reference voltage and the gas-level output voltage, a resistance of variable resistor 29n is adjusted to eliminate the difference in the like manner as above.

Accordingly, in the dry air containing no hydrogen and humidity, this embodiment can reduce variations in the potential differences between  
15 these reference voltages and gas-level output voltages attributable to the variations of the ambient temperature, and therefore it provides an advantage of making highly accurate detection.

The gas-level outputs of DPH 35a and DPL 35b obtained through the above signal processing and voltages appearing at both ends of  
20 temperature sensor elements 1b and 2b are input to microcomputer 32. Microcomputer 32 produces outputs corresponding to hydrogen concentration, humidity and temperature respectively by performing an operation which will be described later.

The gas to be detected in the vicinity of the gas detector, that is the gas  
25 inside the pipe, passes through filter 18 disposed to gas intake opening 17, and reaches GDH 1a, TDH 1b, GDL 2a and TDL 2b. GDH 1a and GDL 2a generate heat in themselves. If the gas being detected contains any of

hydrogen and moisture, temperatures of GDH 1a and GDL 2a change because the hydrogen and moisture change the thermal conductivity of the gas being detected and amounts of the heat taken away from them depending on a level of the concentration.

5      On the other hand, structures of TDH 1b and TDL 2b are such that they are individually sealed inside unperforated casings 11b with dry air.

Therefore, both TDH 1b and TDL 2b produce output voltages at both ends thereof that correspond to the temperatures inside the gas detector, without being influenced by the gas to be detected. These changes are  
10 converted into gas-level outputs respectively by the above method of signal processing, and input to microcomputer 32.

In the first exemplary embodiment, thermistors 8 are used for sensor elements 1a, 1b, 2a and 2b, since they show a high level of sensitivity to hydrogen gas. However, because of the high sensitivity, thermistors 8,  
15 when used, are influenced considerably by the changes in the coefficient of thermal conductivity of hydrogen due to the ambient temperature. It is therefore necessary to make correction of the sensitivity to hydrogen concentration according to the ambient temperature. Since a hydrogen sensitivity conversion factor for each of the gas-level outputs is variable  
20 responsive to changes in the ambient temperature, the correction is made by using a sensitivity correction formula. The sensitivity correction formula is derived from a correlation between voltage outputs across the both ends of each of temperature sensor elements 1b and 2b and hydrogen sensitivity conversion factors under the environment of various ambient  
25 temperatures. For instance, gas-level outputs using a standard gas prepared by mixing 1% concentration of hydrogen in dry air, and voltages across the both ends of temperature sensor elements 1b and 2b are



measured at temperatures of  $-40^{\circ}\text{C}$ ,  $25^{\circ}\text{C}$  and  $80^{\circ}\text{C}$ . The gas-level outputs in the standard gas generally have a tendency to decrease with increase in the temperature, as opposed to the voltages across the both ends of temperature sensor elements 1b and 2b, which can be considered of nearly  
5 a linear correlation.

Therefore, the voltages at both ends of the temperature sensor elements 1b and 2b are also input to microcomputer 32.

Microcomputer 32 performs an arithmetic operation based on the individual gas-level outputs and the voltages at both ends of the  
10 temperature sensor elements 1b and 2b, and produces outputs corresponding to hydrogen concentration, humidity and temperature respectively.

Description will be provided next of the operation performed by microcomputer 32. First, a correction data is established in the following  
15 manner when the gas detector is manufactured.

Initially, measurement is made of gas-level outputs for each of DPH 35a and DPL 35b in relation to changes in hydrogen concentration under the dry air. The measurement is carried out under various temperature conditions. Fig. 6A and Fig. 6B show a result of the measurement under a  
20 condition of  $80^{\circ}\text{C}$  in the ambient temperature. Fig. 6A shows the result of the measurement for DPH 35a on a coordinate plane of the hydrogen concentration in the axis of abscissas and the gas-level output in the axis of ordinates. The gas-level output increases in proportion to the hydrogen concentration, as shown in Fig. 6A.

25 Similarly, Fig. 6B shows the result of measurement of the gas-level output of DPL 35b. The gas-level output of DPL 35b also increases in proportion to the hydrogen concentration. In addition, the voltages across

both ends of the individual temperature sensor elements 1b and 2b of DPH 35a and DPL 35b are not influenced by the state of the gas to be detected, and they both indicate the ambient temperature. The next step is to obtain relations between the voltage values across both ends of the temperature sensor elements 1b and 2b and the gas-level outputs of DPH 35a and DPL 35b respectively. Temperature correction data are then prepared from these data for the sensitivity versus hydrogen concentration. Next, measurement is taken of gas-level outputs from DPH 35a and DPL 35b while varying humidity in the air. Fig. 7 shows the result of measurement under the condition of 80°C in the ambient temperature.

The axis of abscissas represents absolute humidity. The axis of ordinates represents the power output converted into hydrogen concentration. This graph exhibits computation of equivalent value to hydrogen concentration after conversion of the humidity-level output into hydrogen concentration. Curve "A" shows the gas-level output of DPH 35a corrected based on the idea of temperature correction for the sensitivity to hydrogen, as discussed with reference to Fig. 6A and 6B, that is, an error margin of the hydrogen detection accuracy (hereinafter referred to as "humidity offset"). Likewise, curve "B" shows humidity offset obtained by correcting the gas-level output of DPL 35b. In addition, straight line "C" shows value obtained by subtracting the humidity offset of DPL 35b from the humidity offset of DPH 35a (referred to as difference "A" hereafter), representing humidity-level output.

It is apparent from Fig. 7 that there is a difference in the humidity offset between DPH 35a and DPL 35b even though they are under the same absolute humidity condition. This is because the presence of moisture causes a difference in the coefficient of thermal conductivity through water

vapor in the vicinity of the individual gas sensor elements 1a and 2a, of which heating temperatures are different, thereby resulting in the difference of the thermal conductivity between the gas sensor elements 1a and 2a. It is known from Fig. 7 that the humidity-level output, or  
5 difference "A", is proportional to the absolute humidity.

Therefore, by obtaining this humidity-level output, it is possible to make correction of the humidity offset, as well as calculation of the absolute humidity and relative humidity from the condition of the ambient temperature obtained by the temperature sensor elements 1b and 2b.

10 Based on these findings, another step is taken to get a relation between the humidity-level output obtained from the difference "A" and the humidity offset, and to prepare humidity correction data and humidity-level output data for detection of the hydrogen concentration.

Methods of calculating the above temperature correction for sensitivity  
15 to the hydrogen concentration detection and the humidity correction for the humidity-level output and the hydrogen concentration detection are programmed in microcomputer 32. Microcomputer 32 performs the above operations to produce outputs corresponding to the hydrogen concentration and humidity, when it is input with the gas-level output of DPH 35a, the  
20 gas-level output of DPL 35b, and the voltages across both ends of temperature sensor elements 1b and 2b obtained when the gas detector is in operation. Referring to Fig. 8A and Fig. 8B, description is provided of an example of outputs when the above gas detector is actually operated.

In one example of experiment, air samples having absolute humidity of  
25 approximately  $120 \text{ g/m}^3$  were prepared by mixing them with hydrogen gases to various levels of concentration under the ambient temperature of  $80^\circ\text{C}$ , and they were switched one after another in the order of 0%, 0.4%,

0.8%, 1.6%, 0.8%, 0.4%, and 0%. Outputs of the gas detector were then measured after the operation of microcomputer 32. Fig. 8A shows a result of the hydrogen concentration outputs. The axis of abscissas indicates elapsed time during the measurements (in seconds), in which the hydrogen concentration levels were switched in the intervals of 900, 300, 300, 480, 480, 480, 480 seconds. The axis of ordinates indicates calculated value of the hydrogen concentration (%) derived from the gas-level output of DPH 35a, the gas-level output of DPL 35b and the voltages across both ends of temperature sensor elements 1b and 2b, by using the above calculation method. Because the curve in this graph representing the hydrogen concentration shows good response to the changes of the gases, it can be verified that the accuracy is also excellent.

Fig. 8B shows a result of the humidity-level outputs. Like Fig. 8A, the axis of abscissas indicates the elapsed time during the measurements (in seconds), and the hydrogen concentration levels were switched in the same intervals as the above measurement of the hydrogen concentration. The axis of ordinates indicates output of absolute humidity-level corresponding to the hydrogen concentration. The humidity-level output shows no variation in Fig. 8 B, although the hydrogen concentration level has changed substantially during the measurement, as shown in Fig. 8A. In other words, it is clear that the gas detector accurately outputs only the absolute humidity without being influenced by the changes in the hydrogen concentration. Moreover, this level of the absolute humidity agrees with a reading taken on the gas being measured by humidity measuring instrument in the close vicinity of the gas detector. It is obvious from the above results that the gas detector of the first exemplary embodiment can detect both of the hydrogen concentration and humidity independently

with high accuracy.

Another evaluation for detection of hydrogen and humidity was conducted in the like manner as described above, except that GDH 1a and TDH 1b, and GDL 2a and TDL 2b were controlled so that their heating  
5 temperatures are maintained at approximately 190°C and 180°C respectively. The result showed that the gas detector is still capable of making various corrections, although it lowers the accuracy of output value for the absolute humidity.

The gas detector according to the first exemplary embodiment can be  
10 used to compose an apparatus for controlling a fuel cell system and an automobile equipped with it so as to safely shut off hydrogen even if leakage occurs from the system.

(Second Exemplary Embodiment)

In the following second exemplary embodiment, like reference marks are  
15 used to designate like elements as those of the first exemplary embodiment, and description of them will be omitted.

A gas detector of this exemplary embodiment differs from that of the first exemplary embodiment in respects that DPH 35a comprises second TDH 1c, and DPL 35b comprises second TDL 2c, in addition to the structure of the  
20 first exemplary embodiment.

Description is provided in detail hereinafter. In Fig. 9A and Fig. 9B, second TDH 1c and second TDL 2c are each composed of a thermistor, like those of the first exemplary embodiment. Fig. 2 shows a structure.

The structures of second TDH 1c and second TDL 2c are analogous to the  
25 like elements described in the first exemplary embodiment. As shown in Fig. 9A and Fig. 9B, each of the sensor elements is enclosed in unperforated casing 11b in a space filled with dry air, and the unperforated

casing 11b and base 9 are bonded and sealed by projection welding. Second TDH 1c and second TDL 2c thus output voltages across their end terminals according to their respective temperatures inside the gas detector without being influenced by the gas to be detected. Accordingly, the gas detector provides an advantage of detecting gas concentration highly accurately in a wide range of temperatures by adopting the above structure in which combinations of the two temperature sensor elements 1b and 2b, and 1c and 2c are placed inside their respective detector units 35a and 35b.

10 Description is provided next of an operation of the gas detector of this second exemplary embodiment.

As shown in Fig. 10, GDH 1a, second TDH 1c and fixed resistor 40a of  $220\Omega$  are connected in series to form gas detecting circuit 38a. Fixed resistor 40b of  $75\Omega$  and fixed resistor 40c of  $220\Omega$  are connected to each end of TDH 1b in series thereto, to form ambient temperature detecting circuit 37a.

Similarly, GDL 2a, second TDL 2c and fixed resistor 40d of  $500\Omega$  are connected in series to form gas detecting circuit 38b. Fixed resistor 40e of  $320\Omega$  and fixed resistor 40f of  $500\Omega$  are connected to each end of TDH 2b in series thereto, to form another ambient temperature detecting circuit 37b.

In this embodiment here, heating temperatures of GDH 1a, TDH 1b and second TDH 1c are controlled individually to become approximately  $190^{\circ}\text{C}$ .

In addition, heating temperatures of GDL 2a, TDL 2b and second TDL 2c are controlled individually to become approximately  $140^{\circ}\text{C}$ .

25 D.C. power source 31 is connected to these circuits and supplies electric power of 15V.

Describing next pertains to a method of controlling the heating

temperatures constant. In the second exemplary embodiment, three sensor elements 1a, 1b and 1c of DPH 35a, and another set of three sensor elements 2a, 2b and 2c of DPL 35b are so controlled that their heating temperatures as measured in dry air are kept constant without being  
5 influenced by the ambient temperature.

The three sensor elements 1a, 1b and 1c of DPH 35a are controlled in a manner as described hereinafter to make their heating temperatures constant.

Element resistance regulating circuit 36a in DPH 35a consists of fixed  
10 resistor 40g of  $293\text{k}\Omega$ , fixed resistor 40h of  $100\text{k}\Omega$  and another fixed resistor 40i of  $100\text{k}\Omega$  connected in series. A voltage across the both ends of fixed resistor 40i serves as a control voltage.

Ambient temperature detecting circuit 37a comprises fixed resistor 40b of  $75\Omega$  and another fixed resistor 40c of  $220\Omega$  connected in series with TDH  
15 1b at each end thereof. A voltage across the both ends of fixed resistor 40b is a to-be-controlled voltage.

Here, a voltage applied to element resistance regulating circuit 36a, gas detecting circuit 38a comprising the series connection of GDH 1a, second TDH 1c and fixed resistor 41a of  $220\Omega$ , reference voltage circuit 39a and  
20 ambient temperature detecting circuit 37a is regulated through an operational amplifier, a transistor and the like in response to changes in the ambient temperature, so as to equalize the to-be-controlled voltage with the control voltage. Since the resistances of GDH 1a, TDH 1b and second TDH 1c are kept to be constant at all the time as described above,  
25 the heating temperatures of them can be maintained constant.

On the other hand, heating temperatures of three sensor elements 2a, 2b and 2c of the DPL 35b side are controlled constant in the following manner.

Element resistance regulating circuit 36b of DPL 35b comprises fixed resistor 40j of 156k $\Omega$ , fixed resistor 40k of 100k $\Omega$  and another fixed resistor 40l of 100k $\Omega$  connected in series. A voltage across the both ends of fixed resistor 40l serves as a control voltage. Ambient temperature detecting  
5 circuit 37b comprises fixed resistor 40e of 320 $\Omega$  and another fixed resistor 40f of 500 $\Omega$  connected in series to TDL 2b at each end thereof. A voltage across the both ends of fixed resistor 40e is a to-be-controlled voltage.

A voltage applied to element resistance regulating circuit 36b, gas detecting circuit 38b comprising the series connection of GDL 2a, second  
10 TDL 2c and fixed resistor 40d of 500 $\Omega$ , reference voltage circuit 39b and ambient temperature detecting circuit 37b is regulated through an operational amplifier, a transistor and the like in response to changes in the ambient temperature, so as to equalize the to-be-controlled voltage with the control voltage. With the resistances of GDL 2a, TDL 2b and  
15 second TDL 2c kept to be constant at all the time as described, the heating temperatures of them can be maintained constant. Since the ambient temperatures of the individual sensor elements are kept generally uniform, they reduce changes in coefficient of thermal conductivity of the gas to be detected due to the effect of temperature. As a result, this embodiment  
20 provides the gas detector with such advantages that it can detect gas concentration with high accuracy, and shorten a warm-up time because it controls the self-heating temperatures of the individual sensor elements to be constant immediately after the startup of the gas detector.

Describing next pertains to the steps of signal processing to obtain a  
25 gas-level output from each of the detector units 35a and 35b.

In DPH 35a, signal processing is performed in the following manner to obtain a gas-level output. Reference voltage circuit 39a for producing a



reference voltage comprises a series connection of fixed resistor 40m of 293k $\Omega$ , fixed resistor 40n of a resistance value smaller than 100k $\Omega$ , fixed resistor 40o of 100k $\Omega$ , and variable resistor 40p. A voltage across both ends of fixed resistor 40o is taken as the reference voltage. Gas detecting  
 5 circuit 38a comprises a series connection of GDH 1a, second TDH 1c and fixed resistor 40a of 220 $\Omega$ . A voltage across both ends of second TDH 1c is a gas-level output voltage. Signal processing is carried out to obtain a difference in voltage potential between the gas-level output voltage and the reference voltage. If there is a difference between the reference voltage  
 10 and the gas-level output voltage in the air containing no hydrogen and humidity, a resistance of variable resistor 40p is adjusted to eliminate the difference.

Signal processing in DPL 35b is performed in the following manner to obtain a gas-level output. Reference voltage circuit 39b for producing  
 15 another reference voltage comprises a series connection of fixed resistor 40q of 156k $\Omega$ , fixed resistor 40r of a resistance value smaller than 100k $\Omega$ , fixed resistor 40s of 100k $\Omega$ , and variable resistor 40t. A voltage across both ends of fixed resistor 40s is used as the reference voltage.

Gas detecting circuit 38b comprises GDL 2a, second TDL 2c and fixed  
 20 resistor 40d of 500 $\Omega$  connected in series. A voltage across both ends of second TDL 2c is a gas-level output voltage. Signal processing is carried out to obtain another difference in voltage potential between the gas-level output voltage and the reference voltage. If there is a difference between the reference voltage and the gas-level output voltage in the air containing  
 25 no hydrogen and humidity, a resistance of variable resistor 40t is adjusted to eliminate the difference.

Because of the above signal processing, heating characteristics of the

individual gas sensor elements 1a and 2a, and another heating characteristics of the individual second temperature sensor elements 1c and 2c are made nearly equal in their ratios to a variety of temperatures.

As a result, variations in the gas-level output voltage due to changes of the ambient temperature can be suppressed very low. In the dry air containing no hydrogen and humidity, this embodiment can therefore reduce variations in the potential differences between these reference voltages and gas-level output voltages attributable to the variations of the ambient temperature, and it thus provides an advantage of making highly accurate detection.

The gas-level outputs of DPH 35a and DPL 35b obtained through the above signal processing, and voltages appearing at both ends of the individual temperature sensor elements 1b, 1c, 2b and 2c are input to microcomputer 32. Microcomputer 32 produces outputs corresponding to hydrogen concentration, humidity and temperature respectively by performing an operation similar to that of the first exemplary embodiment. Fig. 11 shows the result of evaluation of the humidity characteristic under the condition of 80°C in the ambient temperature. The axis of abscissas represents absolute humidity. Curve "A" shows the gas-level output of DPH 35a corrected based on the idea of temperature correction for the sensitivity to hydrogen, that is, an error margin of the hydrogen detection accuracy (referred to as "humidity offset"). Likewise, curve "B" shows humidity offset obtained by correcting the gas-level output of DPL 35b. In addition, straight line "C" shows value obtained by subtracting the humidity offset of DPL 35b from the humidity offset of DPH 35a (referred to as difference "B"), representing humidity-level output.

It is apparent from Fig. 11 that there occurs a difference in the humidity

offset between DPH 35a and DPL 35b even though they are under the same absolute humidity condition. This is because the presence of moisture causes a difference in the coefficient of thermal conductivity through water vapor in the vicinity of the individual gas sensor elements, of which heating temperatures are different, thereby resulting in the difference of the thermal conductivity between the gas sensor elements.

The humidity-level output exhibited by the difference "B" is proportional to the absolute humidity, as shown in Fig. 11. Accordingly, since it is proportional to the absolute humidity like that of the first exemplary embodiment, it can be used as a humidity-level output. By obtaining this humidity-level output, it is possible to make correction of the humidity offset as well as calculation of the absolute humidity.

Fig. 12A and Fig. 12B show an example of power outputs of the gas detector according to the second exemplary embodiment. A method of this experiment is identical to that of the first exemplary embodiment.

Fig. 12A shows a result of the hydrogen concentration outputs. The axis of abscissas indicates elapsed time during the measurements (in seconds), in which the hydrogen concentration levels were switched in the intervals of 900, 300, 300, 480, 480, 480, 480 seconds. The axis of ordinates indicates calculated value of the hydrogen concentration (in %) derived from the gas-level output of DPH 35a, the gas-level output of DPL 35b and any of the voltages across both ends of temperature sensor elements 1b and 2b and the voltages across both ends of temperature sensor elements 1c and 2c, by using the above calculation method. Because the curve in this graph representing the hydrogen concentration shows good response to the changes of the gases, it can be verified that the accuracy is also excellent.

Fig. 12B shows a result of the humidity-level outputs. Like Fig. 12A,

the axis of abscissas indicates the elapsed time during the measurements (in seconds), and the hydrogen concentration levels were switched in the same intervals as the above measurement of the hydrogen concentration. The axis of ordinates indicates output of absolute humidity-level  
5 corresponding to the hydrogen concentration. The humidity-level output shows no variation, although the hydrogen concentration level has changed substantially during the measurement as shown in Fig. 12A. In other words, the gas detector can output only the absolute humidity level accurately without being influenced by the changes of the hydrogen  
10 concentration.

In addition, this level of the absolute humidity agrees with a reading taken on the gas being measured by humidity measuring instrument in the close vicinity of the gas detector.

This gas detector can provide a sufficiently high accuracy even when it is  
15 used for air conditioning control of a room space in an automobile and the like. According to the above results, it is apparent that the gas detector of the second exemplary embodiment can also detect both the hydrogen concentration and humidity independently with the same high accuracy as that of the first exemplary embodiment.

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## INDUSTRIAL APPLICABILITY

A gas detector of this invention is adaptable for use in a system for detecting hydrogen leakage from an apparatus used in the normal atmosphere since it can detect hydrogen concentration and humidity  
25 independently with respect to each other.